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EIGHTH AND NINTH COMBINED QUARTERLY PROGRESS REPORTS

DEVELOPMENT OF A METHOD FOR FABRICATING METALLIC MATRIX COMPOSITE SHAPES BY A CONTINUOUS MECHANICAL PROCESS

Submitted to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
Contract NAS8-27010
Technical Program Director: Mr. Felix Lalacona, S&E-ASTN-MM

Prepared by

A. P. DIVECHA
S. D. KARMARKAR
P. G. PAWAR

Covering Period From

January 1, 1973

July 15, 1973

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Alexandria, Virginia

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FOREWORD

This Progress Report covers the work performed under contract NAS8-27010 from January 1, 1973 to July 15, 1973. The contract is being performed under the technical direction of Mr. Felix LaIacona of National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama.

ABSTRACT

The continuing efforts in upscaling to produce larger diameter (2", 0.05-8 m) Al/B tubes are described. In a large measure, the increment in length and diameter has necessarily required significant modifications in mat making, preform preparation, heating and sheath removal. While the basic methodology remains unchanged, the larger volume of acrylic binder material and its removal by dissolution in toluene had to be performed by dynamic scrubbing. Similarly, the boron and MCF continuous length requirements increased when a 6 foot (1.828 m) long by 7" (0.1778 m) wide mat was needed. These modifications and associated problems are described fully with schematics. Also included are seven experiments conducted to prepare larger tubes. The thermal profile, drawing speeds and furnace positions in the draw bench bay are presented along with metallographic evidence of composite cross sections.

Effort in the Al/C fabrication via resistance heating was directed towards eliminating objectionable carbides found to exist at composite ends. Simultaneously, preparation of composite rods with uniform cross sections was also attempted. It was determined that sophisticated electrode geometry and mechanical accessories capable of operating in a vacuum environment may be needed to completely eliminate the carbides and the composite cross section non-uniformity. These experiments however, led to development of a 'new' technique involving electron beam heating. It was demonstrated that composite rods (or wires) exhibiting a high degree of cross sectional and distributional uniformity can be prepared. The experimental procedure and the composite microstructures are presented. A possible scheme to enable continuous production of infiltrated yarns via electron beam is discussed in detail.

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1.0 INTRODUCTION

The object of this program is to develop processes capable of producing composites in structural shapes and sizes suitable for space applications. The processes to be explored must be continuous and promise to lower composite fabrication costs significantly. The composite system of prime interest is aluminum boron (Al/B).

Sound metal matrix composites have been produced by numerous procedures such as hot pressing, electro and chemical vapor deposition, plasma spraying, high energy rate forming, powder metallurgy and others. In each technique, careful handling and placement of the filaments precisely is mandatory to achieve uniform interfiber spacing in the finished product. Filament-filament contacts despite extensive care and sophistication, nevertheless occur and the composite integrity suffers.

The present program is based on the ability to mechanically clad the boron filament continuously and uniformly with the matrix. The cladding process requires only periodic checks and up to 5 ft/min (1.52 m) matrix clad filament (MCF) can be produced in one apparatus. Since the cladding thickness can be varied over a wide range, the filament volume concentration can be precisely controlled. Practically any mono or multi-filament species can be clad effectively. The process is particularly suited to boron filaments.

The program is divided into three phases. In the first phase, promising metal working processes, such as rolling, drawing and extrusion are to be explored. Once the processing parameters are established for simple and miniature shapes, the information generated is to be applied in the second phase to produce at least two structural shapes with particular emphasis on hat and tube sections. The third phase to be conducted concurrently with the second, is concerned with detailed evaluation of the full-scale composites.

Another system, namely, aluminum-graphite (Al/C) composites, was added to the current Al/B investigations. The primary objectives of this work are nearly identical to that of its Al/B counterpart. That is, the program is concerned with development of one or more continuous processes capable of producing tubular and other (hats, Z's, T's, etc.) shapes. Most improtant, the experience gained from Al/B investigations is to be incorporated and utilized to the fullest extent.

During this reporting period, Al/B tube fabrication continued. A larger mat making machine capable of yielding 6 feet (1.828 m) long by 6" (0.1524 m) wide MCF arrays was constructed. An alternate approach to mat making was also examined to prepare aligned MCF arrays of triangular cross-section via passage through a die. As discussed herein, the new approach obviates the necessity for continuous MCF lengths. Other aspects including toluene flushing to remove the binder from the preform, resistance furnace and thermal prodile and resulting Al/B microstructures are presented.

Aluminum graphite (Al/C) composites system was given increasing attention. Resistance heating employed fairly successfully earlier was further investigated. Attempts to correct the carbide formation at or near Al/C MCF - electrode contacts and bending observed during infiltration were only marginally successful. It was established that rotating electrodes rather than the existing stationary ones must be employed. The size of the electrodes and their configuration must be optimized to obtain sound composites.

Concurrent with the above, electron beam (EB) heating was investigated. In a relatively short period, fully infiltrated composites were prepared and evaluated metallurgically. Complete discription of the experimental set up and procedure are presented. A more sophisticated system containing take up and supply spools is also presented and discussed.

2.0 2" (0.0508 m) AL/B TUBE FABRICATION

The steps involved in tubular section fabrication are generally defined and established. However, due to the larger diameter and longer lengths now under fabrication, some changes had to be incorporated. For example, a new mat making machine had to be constructed to produce aligned MCF arrays six feet (1.8288 m) in length shown schematically in Figure 1.

This machine, though identical to that employed for three foot (0.9144 m) mats has been found to generate more breaks in the boron filament during mat making. Fortunately, the matrix cladding prevents the MCF fracture; however, the underlying broken filament in the mat are not easily detected. If there are numerous breaks, the mat becomes exceedingly difficult to handle even after spraying with the acrylic binder.

In preparation of a 6.5" (0.165 m) wide mat, on the large six foot (1.8288 m) drum, approximately 4800 feet (1463 m) of boron and MCF material are required in a continuous length. This condition is not readily satisfied because boron length in the "as purchased" condition is often spliced at various lengths. During cladding of the boron with the matrix, it is not uncommon to encounter boron failure once or twice in 3000 feet (914.4 m). These factors coupled with the probability that further breakage can occur during level winding complicates the operation.

While refinements are being carried out to reduce MCF (or boron) breakage, another approach is also presently under consideration. It involves a principle similar to the "pulltrusion" employed in epoxy-based filament composites.

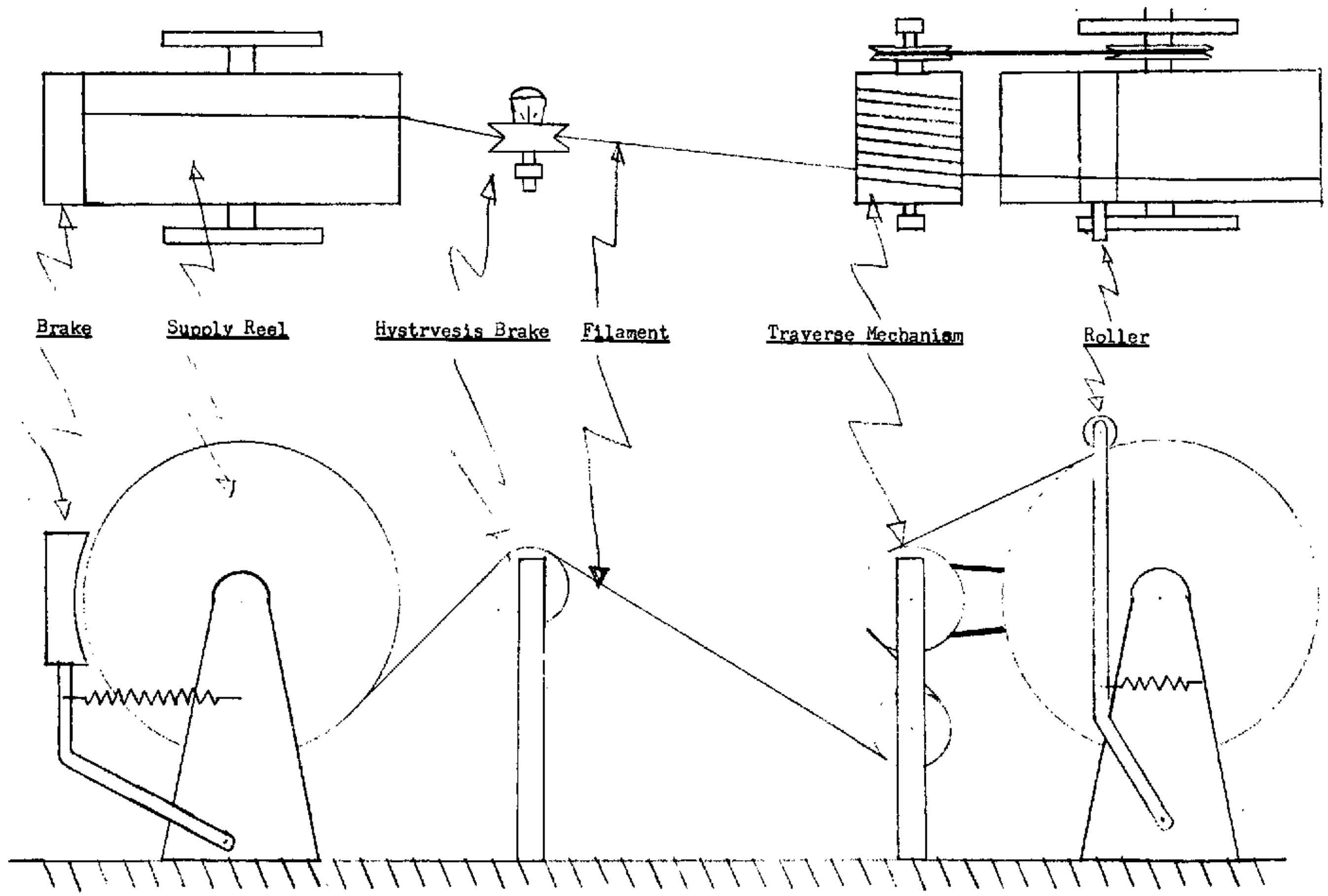

Figure 1. Schematic of Level Winding Machine for Six Foot (1.5388m) Long and 6.5" (0.165m) Wide Mats.

That is, the MCF material is sectioned first into desired lengths. A bendle of MCF's containing a predetermined ends are then passed through a triangular orifice (as shown in Figure 2). At the exit an acrylic spray and a drier help maintain the triangular configuration. For a ten layered composite, a triangular orifice measuring 0.065" (.001651 m) is adequately large to permit passage of a pyramidal array of 45 MCF ends which align nearly perfectly. These may then be positioned on a steel core periphery followed by insertion into a steel sheath as usual.

The primary advantage of the triangular orifice approach lies in the econimical usage of the MCF (and boron) material. There is little wastage of material because even three foot (.9144 m) length can be stored separately to be utilized for smaller sections. Furthermore, the cladding machines can be equipped with knives to cut the MCF material into desired lengths instead of being wound on the take-up spool. A meter synchronized with the knife rotation can yield accurate account of the MCF ends or sections.

Another new aspect introduced due to larger size is that of preform cleaning. While the 1/2" (.0127 m) tube preforms could be cleaned by toluene circulating pump*, the sheer volume increase in preform size necessitated an elaborate set up to insure adequate binder dissolution. Figure 3 shows the new arrangement wherein a scrubbing action from the toluene flow is achieved. The entire preform is placed in a glass tube with its swaged end attached to the discharge pipe. After three hours of cleaning, the toluene is completely drained and recharged with fresh solvent. Near complete binder removal occurs only after this procedure has been repeated three times. Since three to four gallons of toluene are utilized each time, a distillation apparatus (not shown) reclaims 80-85 per cent of the solvent for re-use.

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* 6th Quarterly Report, This Contract

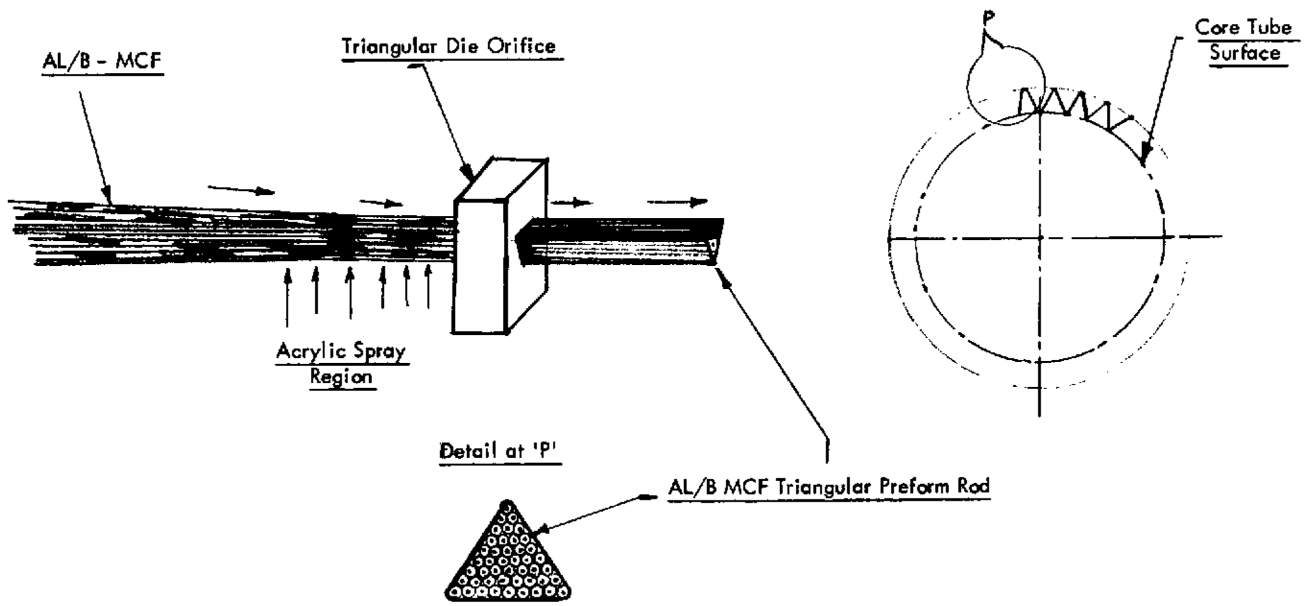

Figure 2. Preparation of Triangular Preform Via Pulling Through an Appropriate Orifice, A Schematic.

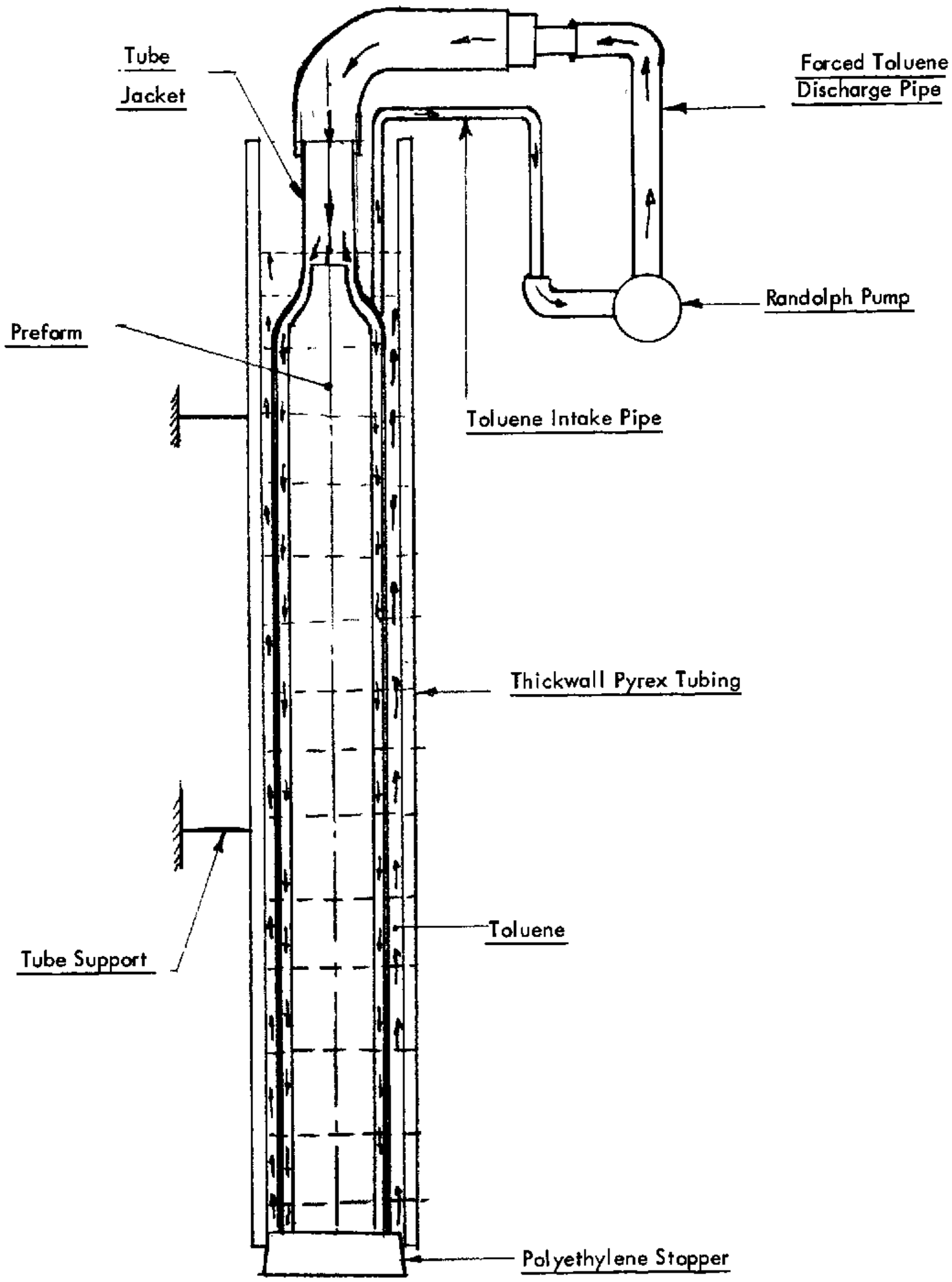

Figure 3. Forced Toluene Scrubbing Apparatus Schematic

Although the preform is virtually free of binder, the toluene must be removed completely before cold and hot drawing. Otherwise residual toluene trapped in the preform may cause problems in diffusion bonding during drawing. Toluene removal is performed in a tubular steel chamber evacuated with a mechanical pump (Figure 4). A furnace kept at 200° C (473° K) expedites the removal in 25 minutes or less. The toluene vapors are condensed in a trap (not shown) in Figure 4.

As mentioned earlier, resistance heating has been substituted for induction heating due to the latter's breakdown and maintenance problems. Considerable effort was expended during this period to achieve rapid heating and temperature uniformity along the preform length. It was necessary to examine various thermal cycles wherein the resistance furance was heated well above the required temperature to reduce the soaking time below 10 minutes. The most reliable heating cycle, however, appeared to be one in which the soaking period was 12-15 minutes, which is a much faster heating cycle than that involving 25-30 minutes encountered in initial experiments.

Since a single furnace was incapable of achieving the desired results, a separate "booster" furnace was added as shown in the overall schematic in Figure 5. Two thermocouples were positioned to monitor temperatures at strategic locations. The larger furnace was mounted on tracks inside the draw bench bay so that after each draw, it could be quickly moved to the right. The tubular preform loading was thus rendered easy. More important, the waiting period between draws was reduced to two minutes for the preform to get to the desired temperature. Thus, the "booster" furnace keeps the die at a reasonably high temperature (300-350° C, 573-623° K) to prevent preform quenching. Furthermore, it can be maintained at higher temperatures to accept larger preforms without changing the main, movable, furnace temperature appreciably.

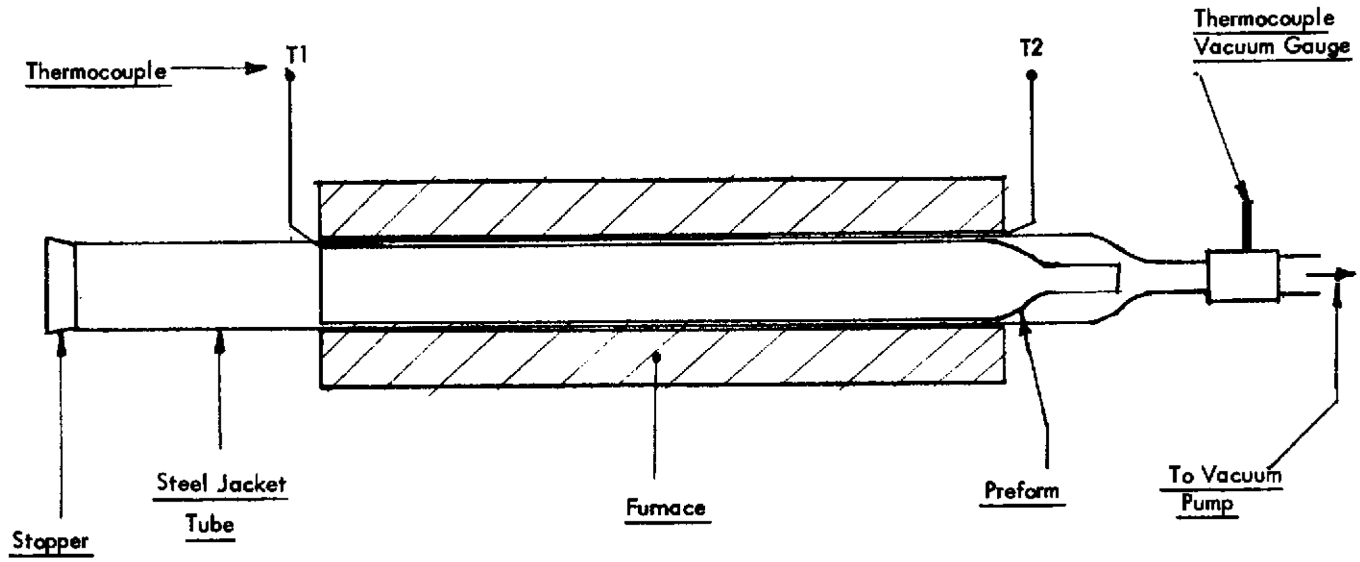

Figure 4. Toluene (or Solvent) Removal from Tubular Preform Via Vacuum and Heat

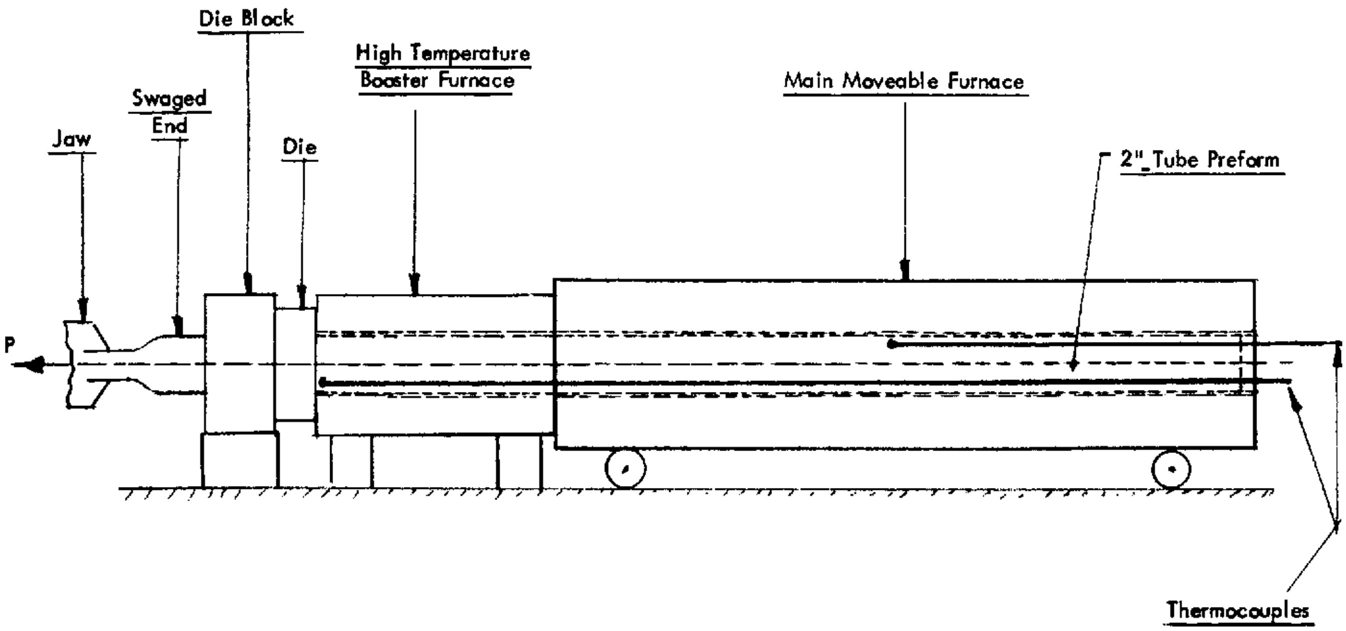

Figure 5. Arrangement of Resistance Furnaces Located in the Draw Bench Bay (not shown) for Hot Drawing of 2" (0.0508m) Tubes, A Schematic.

Three dummy preforms measuring 3, 5 and 6 feet (0.9144 m, 1.524 m and 1.828 m) have been preformed to yield a reasonably consistent temperature profile. That is, before an experiment is performed on a particular size tube, the dummy preform measuring the exact length of the composite preform is drawn through a die, thus closely simulating the thermal conditions which would be encountered in the final experiment with the composite preform. This practice, though admittedly time consuming, assures that the apparatus is functioning adequately. A typical temperature distribution of the tubular preform three feet (0.9144 m) in length is shown in Figure 6. The average temperature is 1000° F (538° C) at the die entry when the speed is 0.33 feet/minute (0.10 m/min.).

Steel core and jacket removal has also required modifications due to increased length and diameter. While outer sheath is relatively readily removed in the HNO_3 bath, the acid supply to the core must be maintained by circulation via the Randolph pump. This is schematically shown in Figure 7.

Although seven tubular preforms were prepared during this period, only two could be hot drawn. This was attributable to mat non uniformity and attendant difficulty in maintaining the steel core and sheath coaxial with respect to each other. It was also observed that the core tube collapsed during cold drawing as the drawing forces were not uniformly distributed on the core periphery. This effect had also been previously encountered with smaller diameter tubes (3rd and 4th quarterly reports, this contract).

Several problems remain as yet to attain complete consolidation, wall thickness uniformity, and sheath and core removal. Figures 8 and 9 are representative cross sections showing fair and poor consolidation.

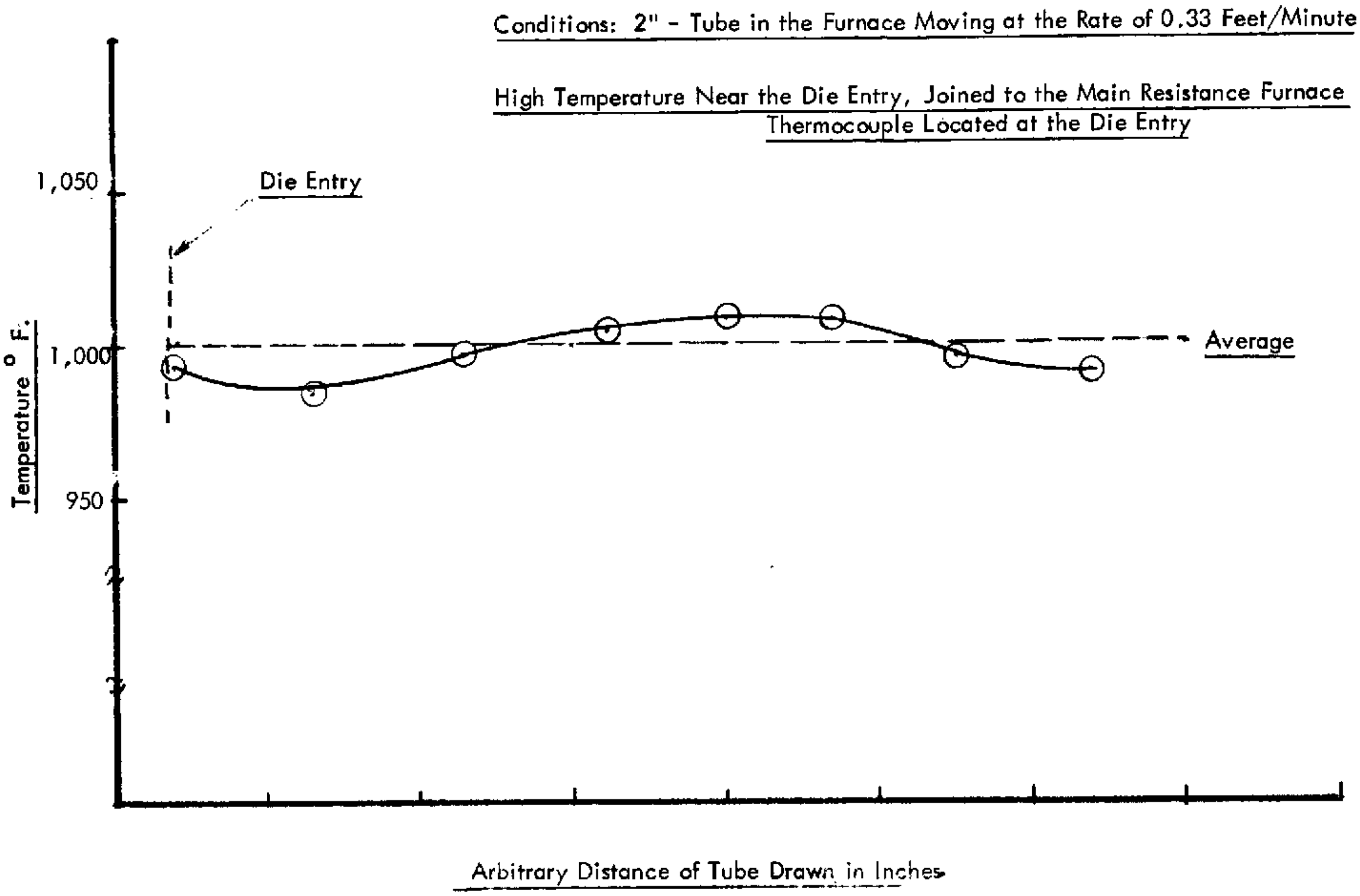

Figure 6. Temperature of the Tubular Preform at the Die Entry

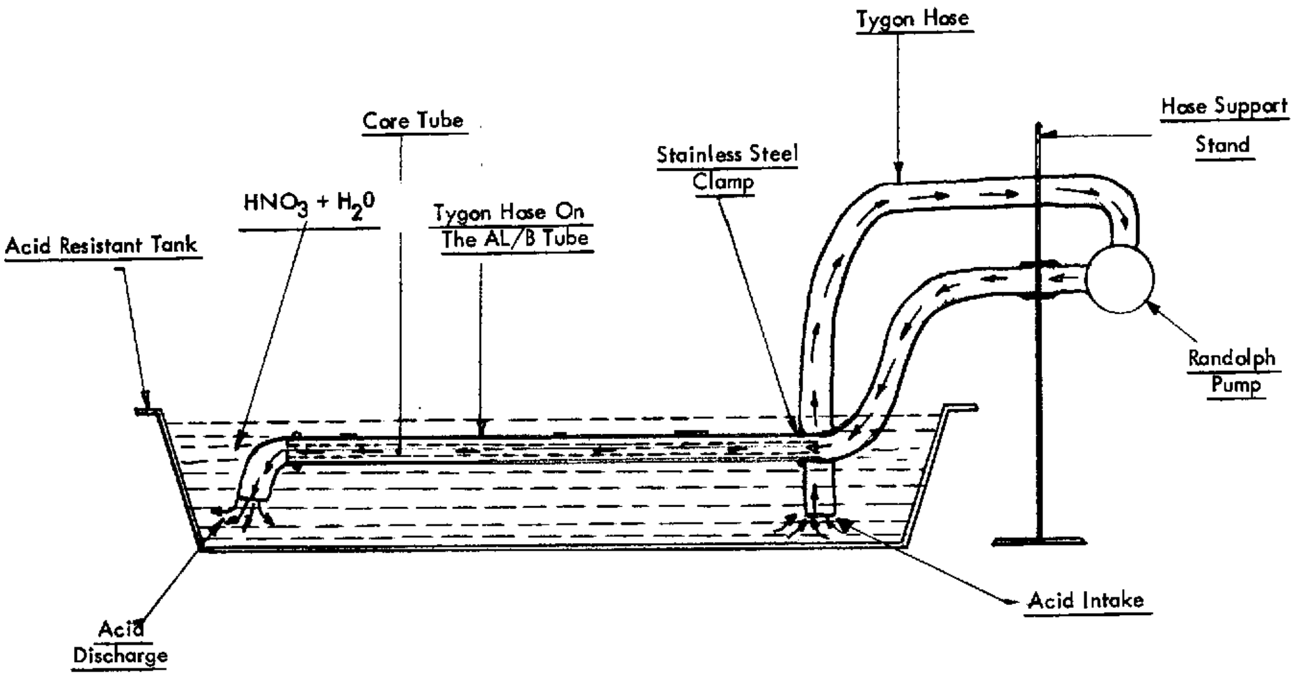

Figure 7. Schematic of Steel Core and Jacket Etching Bath

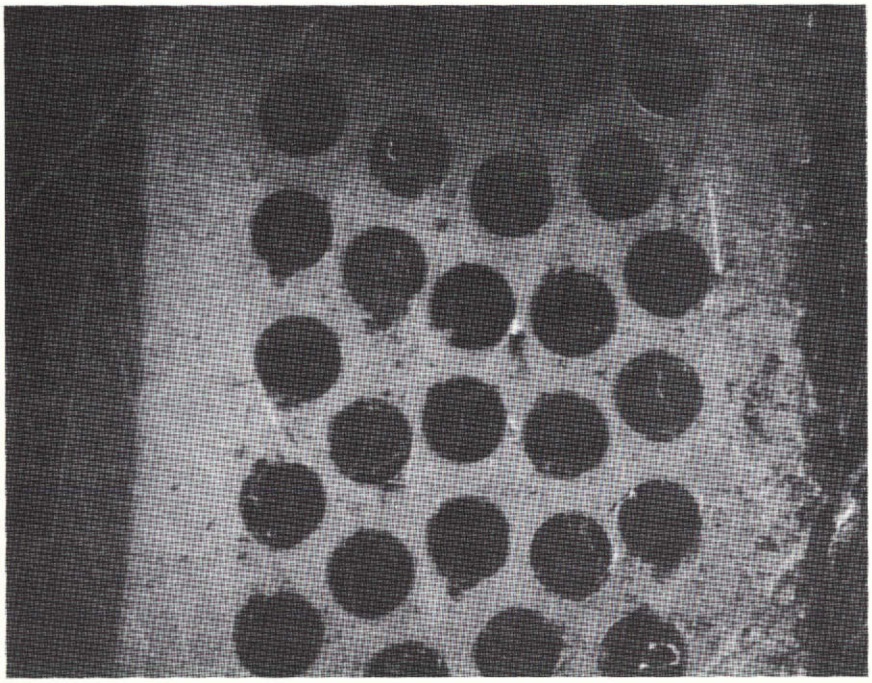

FIGURE 8 Poor Consolidation and Filament Distribution Along the Circumference are Seen in this Composite Tube. As Polished, Dark Field, 80 X. (See also Figure 9)

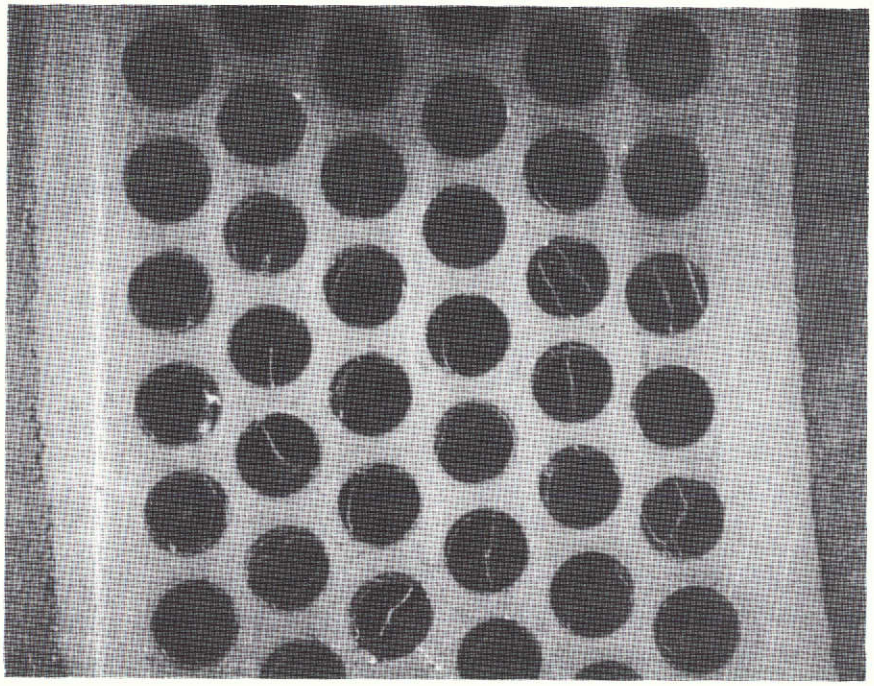

FIGURE 9 In Other Areas (Diametrically Opposite to the Section of Figure 8), Filament Distribution is Adequate and Consolidation, Though Not Complete, is Far Superior. As Polished, Dark Field, 80 X

along the tube periphery. Figure 8, for example, shows many pores and filament array disruption. Only five layers are observed as compared to evenly distributed and fairly well consolidated array shown in Figure 7. Other areas show reasonable distribution though matrix - matrix disbonds are indicated (Figure 9) in some areas.

A careful analysis indicates that the major problem lies in the MCF mat perfection (or lack of it). Although considerable care is exercised in preform and preparation, the mats exhibit some curvature (and filament movement) when folded around the steel core. Boron filament by itself also has a curvature which tends to aggravate the problem. Mat making improvements and other approaches such as triangular 'pulltrusion' are also being considered as possible means to prevent the effects observed in the final product.

3.0 ALUMINUM - GRAPHITE (Al/C) COMPOSITES

Efforts were largely concentrated towards improving the resistance heating process which had shown promise during the previous period. One of the aspects examined was the prospect of automating the process in accordance with the program objective.

As more experience with graphite is accumulated, it appears that a two step process may be more expedient. That is, it may be necessary to consolidate the matrix - clad - filaments in a wire or rod or tape form first, followed by secondary fabrication to produce tubes or hats, etc. A single Thornel 50 (1 or 2 ply) yarn clad with a matrix may be processed initially into a continuous consolidated wire and then bonded together into a shape in a way the aluminum boron composites are made. The main difference in the two systems could be the fabrication temperature which may be at a level where some matrix metal is liquid to permit fusion between the individual composite elements. Experiments being conducted and those which are planned take into consideration the future needs that may arise to enable composite shape preparation.

3.1 COMPOSITE FABRICATION

As reported previously, hot pressing and hot drawing were found largely inadequate to yield fully infiltrated composites. The problems were concerned with the inability of the (partially) liquid metal matrix to penetrate the bundle in a reasonably short period. Nickel coated filaments improved the penetration; however, only filaments at the bundle periphery were infiltrated leaving majority of the filaments in the center devoid of the matrix.

During this reporting period, efforts were largely aimed at improving several inconsistencies in the resistance heating method described in the previous report. For example, first, the composite wire cross section was found to be of an irregular shape. Second, thermal expansion difference between the composite components (aluminum and graphite) was sufficiently large so that as the composite preform temperature increased, the preform invariably began to bend. Third, the wattage value (as indicated by an ammeter and voltmeter) fluctuated widely from 200 to 1000. Lastly, aluminum carbide was found to exist at the two extremeties.

Concurrent with resistance heating, another method, namely electron beam heating was also examined during this period. The reasoning that prompted this investigation was based on the possibility that electron beam characteristics are likely to be similar or superior to those of resistance heating. Its most important characteristic is highly localized and controlled heating. Several advantages may be derived from electron beam. First, since the preform is heated at one spot at any given time, the thermal expansion difference in the composite components may not create the bending problem associated with resistance heating. Second, the preform volume is relatively constant for a unit length, the power input to cause melting may be held fairly constant. This aspect may permit continuous processing more easily than resistance heating wherein the electrical conductivity per unit length may vary widely. Third, the depth of penetration due to the electron beam may also be advantageous in bringing about rapid bundle infiltration. Most important, if electron beam heating proved successful, carbide formation which occurred in the composites' extremeties in resistance heating could be totally avoided. This is significant because attempts to modify resistant heating set up to prevent filament degradation (through reaction with aluminum) were only partially successful. In contrast, the preliminary experiments with electron beam showed complete absence of carbide throughout the composite length. The experiments with resistance heating and electron beam heating are described below.

3.1.1 RESISTANCE HEATED COMPOSITES

A 6061 Al-Thornel 50 composite with our irregular cross section is shown in Figure 10. The large matrix area is inexplicably segregated while some voids appear in the relatively well distributed composite section. Carbide formation is totally absent in this composite when examined at higher magnifications. In other areas in close proximity to the electrodes, carbides could be readily detected.

Two approaches to prepare larger composites from these small cross section rods were examined. One involved inserting the infiltrated rods into an aluminum sheath followed by cold and hot drawing in much the same fashion as Al/B rods are prepared. Second method was that involving hot pressing at temperatures above the matrix solidus.

Three drawing experiments were conducted with infiltrated rods jacketed in aluminum sheath. In contrast to Al/B system wherein upwards of 66% cold reduction can be imparted, the bends in the infiltrated rods precluded significant cold deformation. Hot working was possible although composite fracture occurred even when the temperatures were above the matrix solidus. The difficulties were compounded due to oxidation and uneven deformation of the sheath material. Sheath necking occurred unpredictably and this in turn caused premature failure at the die entry.

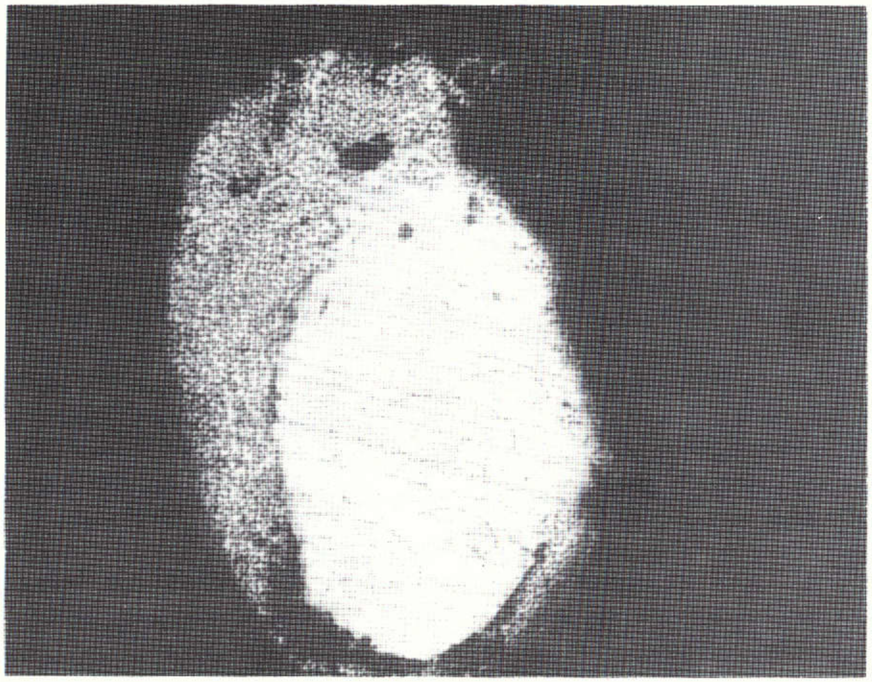

FIGURE 10 A 6061-Thornel 50 Composite Cross Section, As Polished, 80 X, Bright Field

Hot pressing (in air) also failed to yield satisfactory bonds at rod interfaces even though placement of the rods in the die was more uniform because it could be manipulated more accurately than in cold drawing operation.

Resistance heating experiments continued with the objective of producing a rectangular (or an oval) shaped cross section. This was achieved by adding a step in the preform preparation procedure. After cold drawing the MCF bundle in an aluminum jacket as usual, the round preform was rolled to an oval shape. It was reasoned that if the oval configuration could be maintained after infiltration, it may be easier to produce a larger composite by stacking these oval shaped sections and hot pressing to bond the interfaces. As compared with round rods, the oval or square shaped composites would enable packing with very few voids. Bonding at interfaces would be thus rendered easier than circular rods which when close packed contain 26 per cent voids. Furthermore, if a cold rolled preform remained flat after infiltration, it is conceivable that a 6" (0.1524 m) wide sheet could be prepared followed by a press brake operation to convert the flat into a Z or a hat.

Several experiments were conducted to evaluate this approach. The cold drawn, round, preforms were cold rolled into an oval taking care that fiber fracture was avoided. An example of a typical cross section is shown in Figure 11 which resembles a polygon. This composite which had 7075 Al matrix, a 7075 Al jacket (or sheath) and five nickel coated Thornel 50, 2 ply yarns, showed adequate bundle infiltration and massive matrix rich areas. As usual, the areas near the electrodes contained carbides and the composite "rod" displayed non-uniformity.

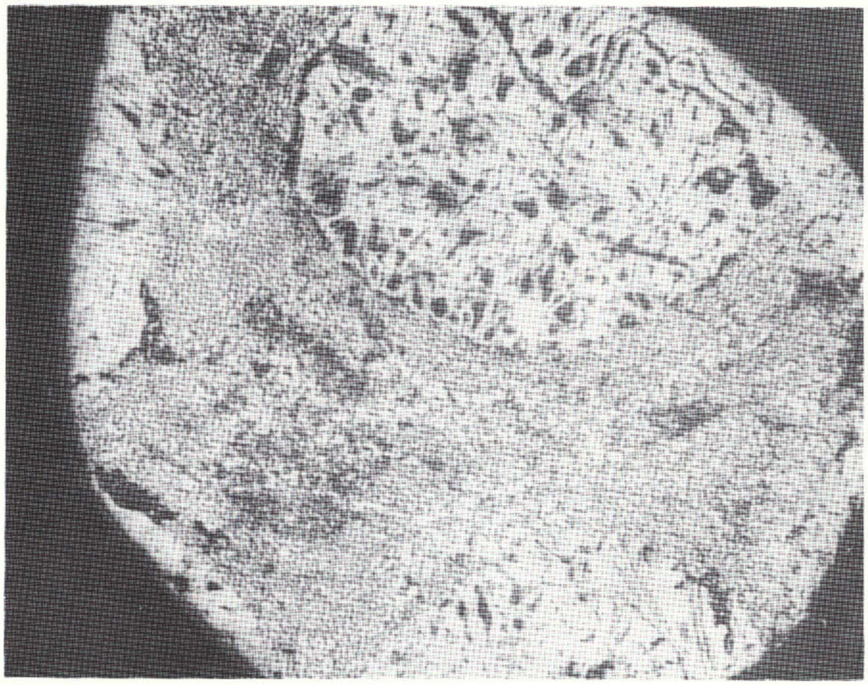

FIGURE 11 A 7075-Thornel 50 Composite Cross Section, Bright Field, As Polished, 80 X

In conventional resistance seam welding, the electrode design and material are critical. The electrodes resemble rolls and rotate in unison in a fashion to the rolls in a rolling mill. In production seam welding, the rolls are sometimes as large as 10 to 12 inches (0.254 - 0.3048 m) in diameter and can be manipulated mechanically to apply desired forces on the work to be welded.

These experiments, though totally not successful, yielded valuable information. For example, they strongly indicated the need to produce straight and uniform cross section composite rods or, alternately, develop process(es) which would preclude a secondary fabrication step involving bonding of many smaller composites. The fact that the resistance heated composites which were "carbide free" initially showed minute carbides formation at the interfaces in some areas after hot pressing further emphasized the advantages of fabrication of shapes in one step. This does not imply that secondary fabrication is not possible; however, fabrication costs with at one step process are likely to be lower than one involving additional intermediate operations.

A brief literature and product manufacturer survey was conducted to ascertain the degree of sophistication required to design a system comprising of rotating electrodes which would operate satisfactorily in vacuum. Although relatively small electrodes (2" diameter, 0.0508 m) are required for the purpose, the rotary drive, and motor attachments for vacuum environment were found to involve time and capital expenditures which could be justified only after significant assurance and evidence of the process feasibility has been gained. Experimentation is continuing with the existing equipment.

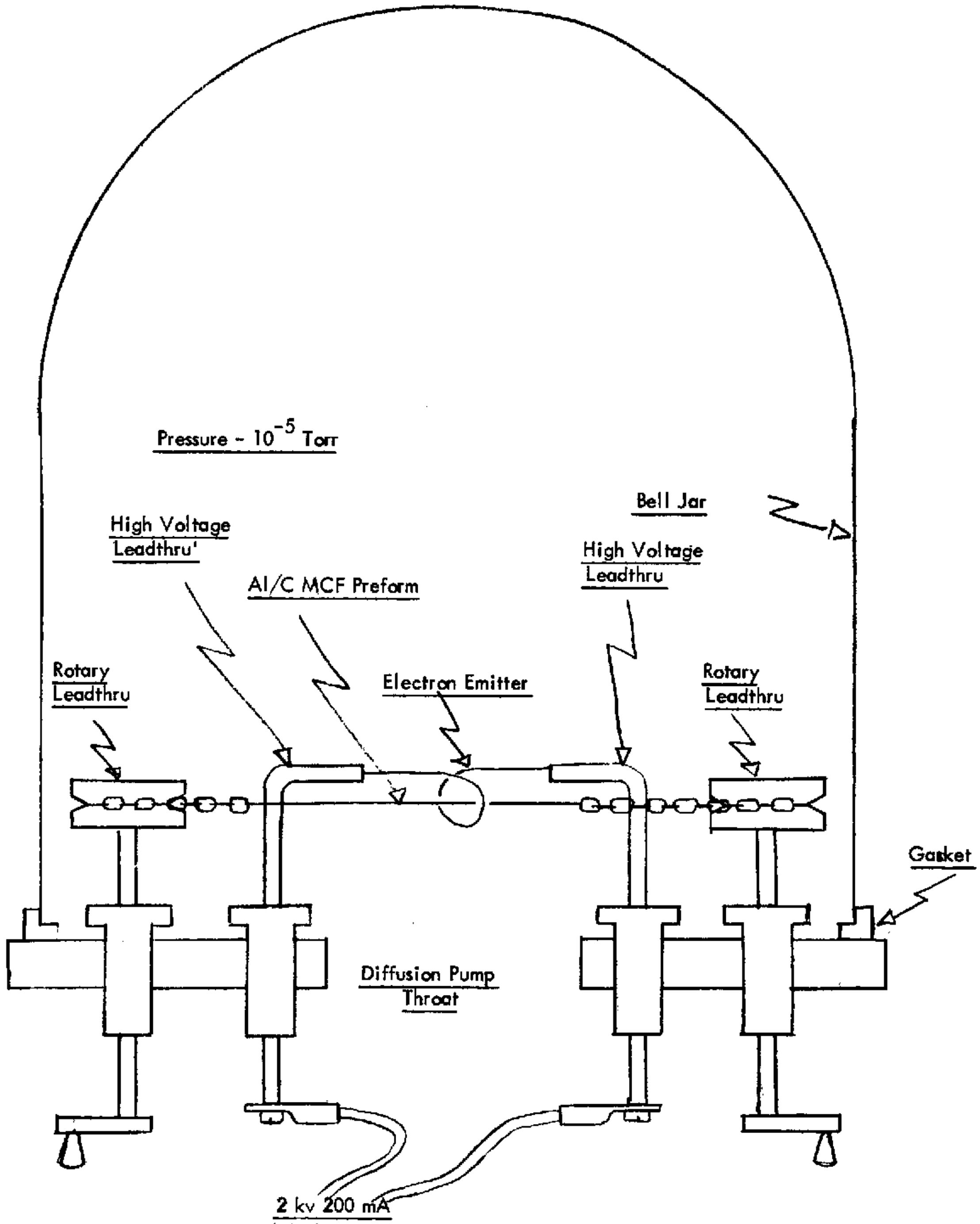

Figure 12. Electron Beam (EB) Apparatus for Fabrication of Al/C Composites, A Schematic

It appeared that while resistance heating had shown promise as a fabrication method, other methods must not be ignored particularly when they can be applied more effectively. For example, the experience with resistance heating certainly showed that carbide formation occurred only in those areas where melting initiated due to high contact resistance. Elsewhere along the preform length the aluminum melted gradually without reaching very high temperatures. Given a heating method or source which is capable of heating a very small area of the preform, the temperature control would be enhanced appreciably.. Since a small preform portion is being heated, the thermal expansion and electrical conductivity differences between graphite and aluminum could be made to play minor roles in composite fabrication.

A well known method, namely, electron beam heating satisfies all these conditions including the vacuum environment. The basic experimental set up requires a bell jar system evacuated by diffusion and mechanical pumps to 1×10^{-4} torr or better. In resistance heating, the same system was utilized. In other words, electron beam experiments could be conducted without delay and without neglecting resistance heating experiments.

3.1.2 ELECTRON BEAM AS A MEANS OF COMPOSITE FABRICATION

A simple electron beam (EB) set up has been devised to conduct these preliminary experiments. As seen from the apparatus schematic in Figure 12, it comprises of a tungsten filament which acts as an electron emmitter. It is in the form of a loop approximately 1" (0.025 m) in diameter. The composite preform is 'threaded' and attached to the two pulleys via a wire as shown. The two pulleys can be manipulated manually during the experiment to move the filament horizontally in either direction.

In a typical experiment, the eintire bell jar is evacuated via a diffusion pump and a mechanical pump. Since electron beam operates efficiently at low pressures, experiments are conducted when a reading of 1 X 10^{-5} torr is achieved in the bell jar.

Although this method has been under investigation for a relatively short period, it has been possible to conduct well over 50 experiments enabling rapid accumulation of important data. For example, it is now know that:

1. 6061 and 7075 exhibit infiltration characteristics superior to other alloys, namely 2024, 1100, and 4043.
2. The electron beam (EB) must not 'see' the Thornel 50 or the graphite filament along its entire length. If a discontinuity in the cladding exposes the filament (or the coating on it) to the electron beam, excessive current is drawn and the power supply shuts off automatically.
3. The temperature rise in the preform at localized area where the electrons bombard the matrix is very rapid even at low power input levels. Consequently, the aluminum is rapidly evaporated thus exposing the underlying graphite filament. The advantage of this phenomenon is that composite fabrication can be conducted at high speeds. The disadvantage, at least at the present, is that the multiple matrix cladding is required in order to assure adequate aluminum for filament bundle infiltration. In some cases, as many as 10 layers or claddings of the matrix have been utilized.

5. Since EB power input is only 300-600 watts (or 1500 volts at 200-400 milliamps), larger composites containing greater overall matrix volume should not present insurmountable difficulties. This is particularly significant because, with proper focussing of the beam with magnetic lenses, the efficiency should improve by at least 50-60 percent.

The primary deterrent topreparation of longer composites at the present time is due to the small bell jar size. The pulleys shown in Figure 12 schematic are 1" (0.025 m) in diameter. Any larger pulley would interfere with the bell jar seating on the base plate. After passing through the EB, the preform is very stiff even when only one Thornel 50 yarn is involved. Take up spool diameter which would accept the infiltrated composite without breakage must be at least 6 inches (0.452 m). To incorporate a larger spool, the bell jar height (and diameter) must be increased appropriately. Plans have already been formulated to acquire components including a larger bell jar, higher voltage feed thrus, mechanical drives, etc. A schematic of the proposed system is shown in Figure 13.

Although various matrix alloys and preform configurations have been evaluated in conjunction with EB, it has not been possible to perform adequate tensile tests due to the short lengths fabricated in the present system. However, considerable metallographic evidence has been generated which show that carbides are absent in the entire composite length. It is also observed that the degree of infiltration and cross sectional configurations of composites prepared by resistance heating

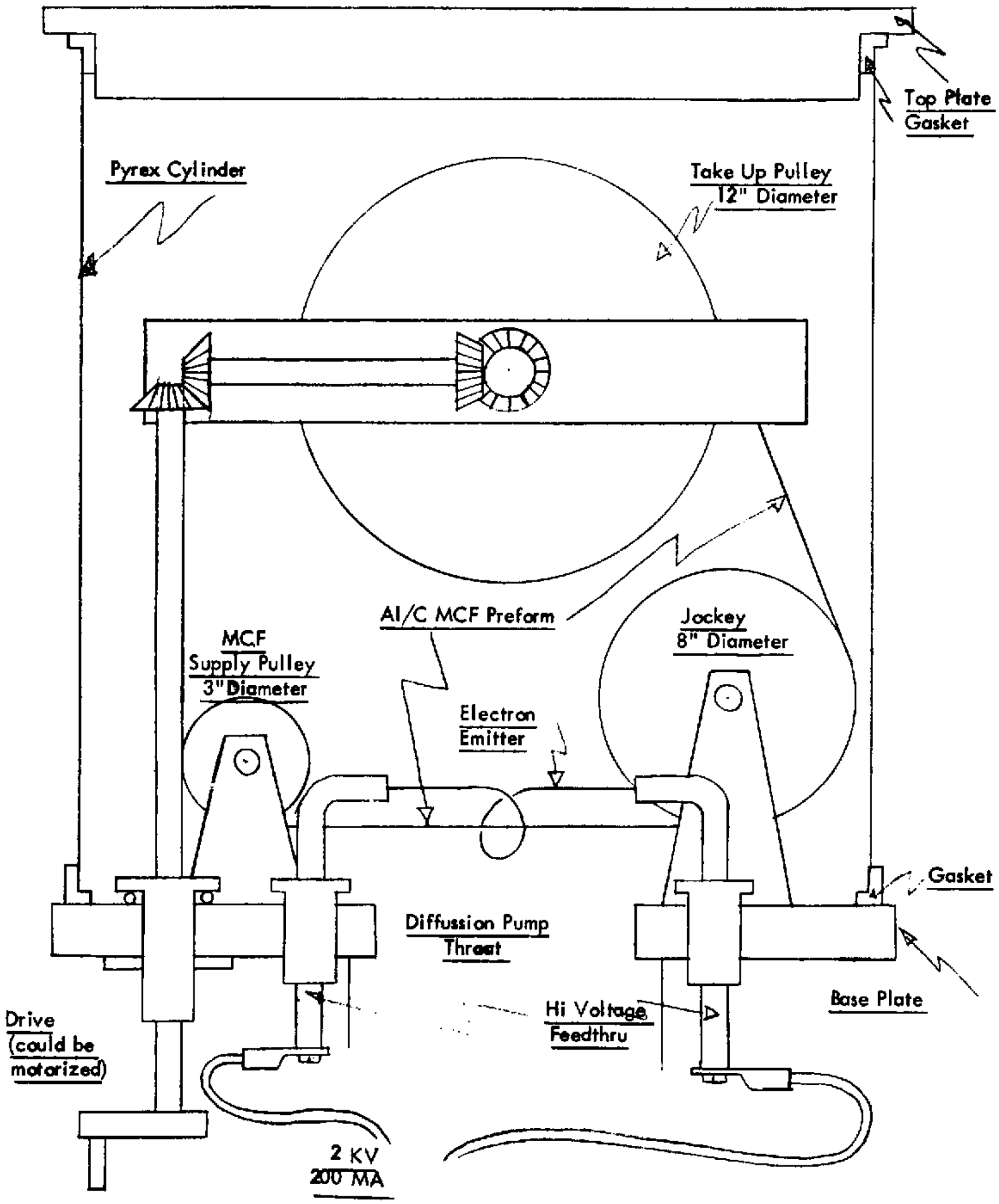

Figure 13. Improved EB Apparatus With Take Up and Supply Spools for A l/C Tape Fabrication

and EB heating resemble each other in many aspects. The exception is the incidence of carbides at the composite ends with the resistance heating and complete freedom from interaction in the electron beam method.

As mentioned earlier, the energetic electrons rapidly removed the usual single cladding, (0.0015" or 0.002" (0.0000381 m or 0.0000508 m) thick. When sufficient or excess cladding was provided, however, Thornel 50 yarn was well infiltrated (Figure 14). In this photograph, the excess cladding can be seen on the yarn periphery. There is good filament distribution and perhaps more important, the bundle cross section is a fairly uniform circle. The straightness of infiltrated yarns has also been improved substantially. It will be recalled that this was not readily achieved in the resistance heated composites. The main deterrent to obtain completely uniform composites by EB at the present time is wholly attributable to the manual feed-thrus. That is, the operator has to rotate the pulleys with perfect coordination to move the preform to the left or right (Figure 12) while maintaining tension. A slight slack results in uneven electron bombardment or input because the preform axis does not remain at the tungsten filament center. It is perhaps due to off-center position that the aluminum cladding appears non-uniform in Figure 14. More aluminum is exhausted (or evaporated) in one area along the circumference than elsewhere because it (the area) was closer to the filament. Despite this difficulty, the yarn is well infiltrated. The unique heating character of electron beam is believed responsible.

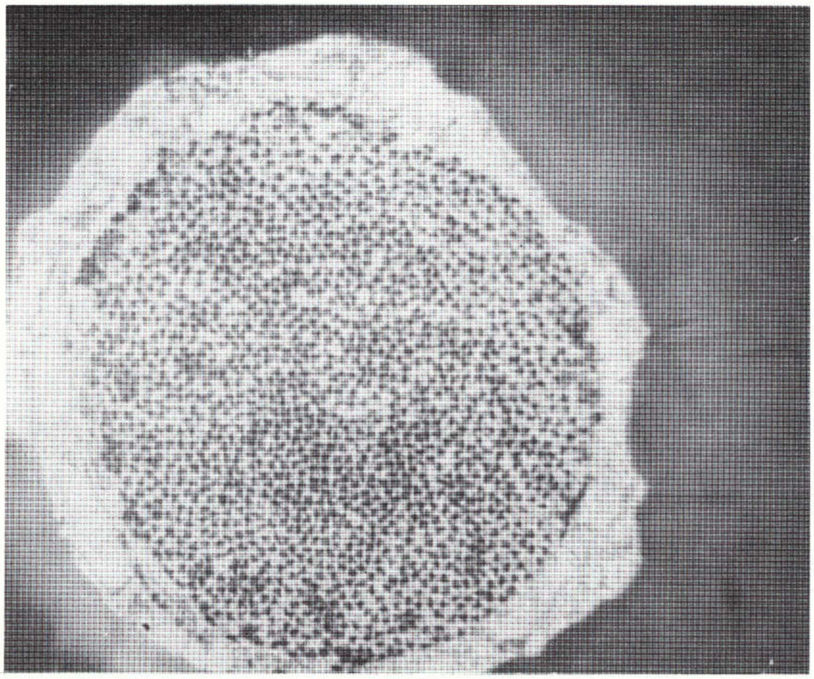

FIGURE 14 4043 Al-Thornel 50 Composite Showing Relatively Uniform Cross Section, As Polished, Bright Field, 100 X

Several attempts were made to prepare multiple yarn containing composites. A typical example is shown in Figure 15. wherein five infiltrated yarns and large matrix rich areas are indicated. The five matrix cladding layers on each bundle are not visible as in Figure 14. But some voids are visible in the matrix rich areas. This specimen is also not polished properly due to difficulty in sectioning prior to mounting.

It is reasonable to state that resistance heating and electron beam are viable methods for aluminum graphite composite fabrication. Since EB heating does not involve 'physical' contact with the specimen (as in resistance heating), the thermal expansion difference between the composite components is precluded. Filament damage is thus nearly completely avoided. Other advantageous features of EB are extremely good thermal control, chemical inertness (of electrons), and the speed of infiltration. If welding speeds employed in conventional electron beam welding apparatusses is a guide, 100-140 inches/minutes (2.54-3.56 m/min) are not uncommon. The ability to deflect electron beams at will via magnetic lenses is also an asset and may be appropriate for tubular and hat section fabrication.

As mentioned earlier, plans have been formulated to 'upscale' the composite production facility to enable preparation of longer and larger samples. During the next period, fabrication experiments will be continued in the existing equipment while larger chamber will be procured for installation. Feed-thrus, motors for automatic feed have already been tentatively selected. It is anticipated that the modified, larger, system will be operational. Among the first experiments schedules is one involving preparation of a short and small diameter tube to yield preliminary information regarding fabrication parameters.

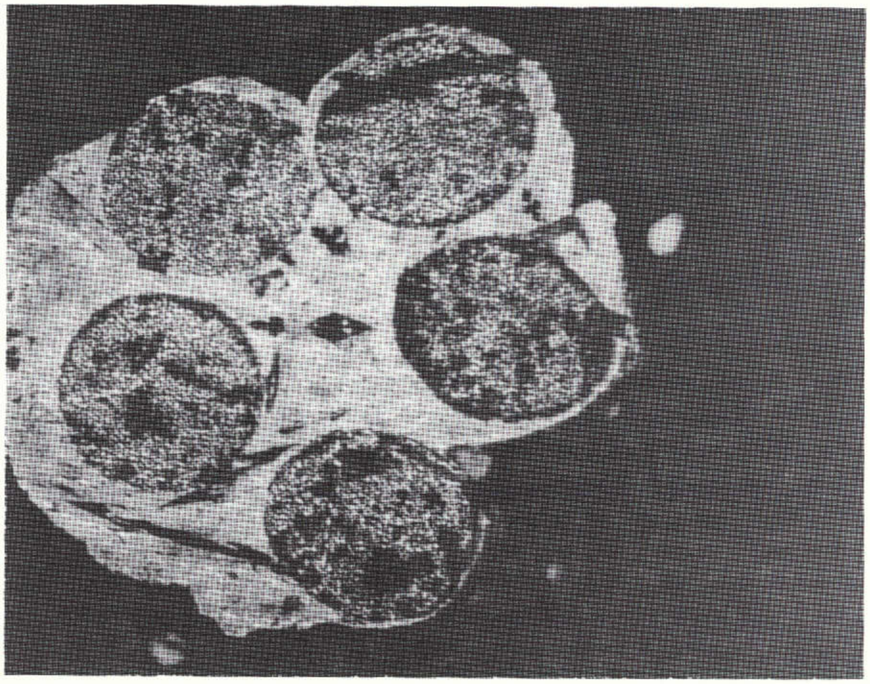

FIGURE 15 A 4043 Al-5 Thornel 50 Yarn Composite Cross Section, As Polished, Bright Field, 80 X

4.0 FUTURE WORK

Al/B System

At least one, 5 foot (1.524 m), 2" (0.0508 m) diameter tube will be prepared and evaluated. It is contemplated that a significant portion of this tube will be available for delivery to MSFC for evaluation.

Al/C System

Resistance heating and electron beam methods will continue to receive attention. Emphasis will be placed on one as soon as convincing evidence for its applicability to composite fabrication is established. This will be followed by a small tubular composite fabrication scheme to demonstrate the ability of the selected method to produce composite shapes.